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30558

MEMORANDUM FOR PR (In-House Publication)

FROM: PROI (TI) (STINFO) 30 November 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-1999-0228**
Strakey, P., "Injector/Combustor Technology" (BFI)

49th JANNAF Propulsion Meeting (Tucson, AZ, 14-16 Dec 1999) **(Statement A)**

BRIEFING FOR INDUSTRY
16 Dec 1999

Injector/Combustor Technology

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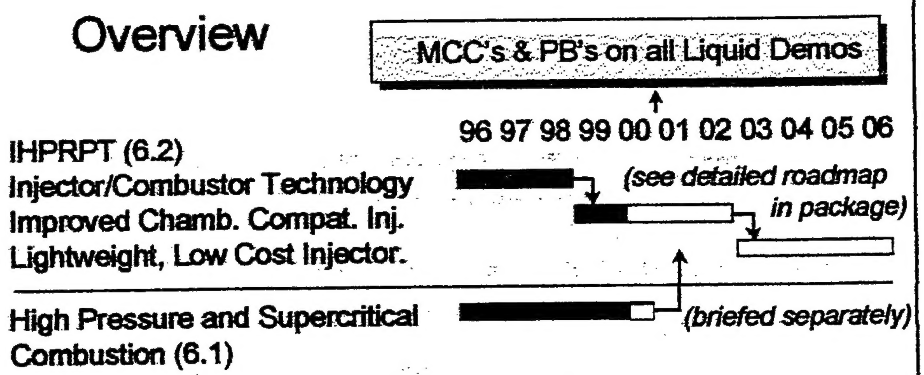
Overview



Funding ($1,000's)	Prior	99	00	01
6.2	4453	973	764	764

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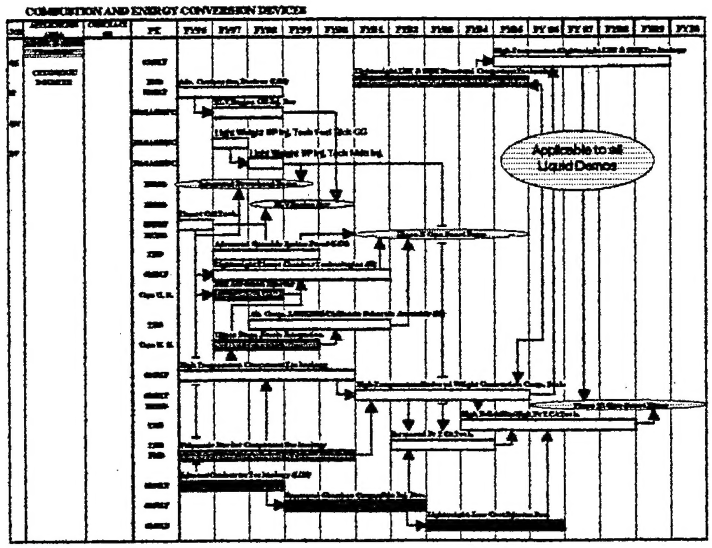
IHPRPT Roadmap



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6.2 Objectives

- Develop tools to predict the effect of injector design changes on liquid rocket performance.
- Provide flexible, low cost screening of candidate injector designs.
- Reduce film cooling requirements without sacrificing combustion chamber lifetime or reliability.

The Problem

- Combustor designers are unable to adequately predict whether all design criteria will be satisfied.
- Problems not discovered until full scale testing tend to be extremely expensive to fix, and usually require sacrificing engine performance* and/or lifetime.*
- Most past engine development programs have encountered such problems.

* IHPRPT goals

Required Injector/Combustor Characteristics

- Complete combustion in the shortest possible length
  - Main injectors: performance vs weight tradeoffs
  - Preburners/GG's: downstream component interactions, eg, turbine blades, etc
- Acoustically stable
  - Chamber modes
  - Feed system coupling
- Chamber/wall compatibility
  - Heat transfer/cooling
  - Oxygen blanching
- Minimize pressure drop
- Throttling
- Ignitable; minimum ignition transients
- Cost, weight
- The "ilities:"
  - Reliability
  - Maintainability
  - Manufacturability
  - Durability
  - Operability

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Technical Approach

- Develop design guidance at the _subscale_ level. Use data to
  - *Develop models.*
  - *Anchor codes.*
  - *Screen candidate designs.*
- Assess the _direct_ impact of design on relevant parameters (e.g., mixing) via windowed access, as appropriate.
- Improve scalability by make all facilities _high pressure_ capable (1500-2000 psi).

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Payoffs

Provide alternatives to trial and error development

- _Performance:_ Injector related design uncertainties translate to 3-6 sec Isp on a booster class LOX/H2 engine.
  - Comparison: IHPRPT 2010 Isp objective is 13.5 sec.
  - 3-6 sec Isp buys 1.6 - 3.3 _tons_ payload on the Space Shuttle Main Engine (SSME) worth $20-40M _per launch._
- _Operability and Lifetime:_ Injector related performance deficit required SSME turbopumps to be run at 105% rated power, increasing pump stress.
  - Pumps are the most expensive SSME maintenance item.
  - Turb. blade cracking problem is also probably inj. related.
- _Instability:_ Injector related Saturn F-1 instability problem required over 800 full scale tests to solve.
  - Present day costs: over $750K per test. Total: $600 million.

Trial-and-error approaches risk significant cost overruns that can no longer be afforded

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Relationship to IHPRPT Goals

B&OT Goal:	C&EC Tech. Obj.	Inj./Comb. Task*:
Increase Isp (3% cryo, 17% HC)	Incr. Isp. Eff. 5%	a. Reduce film cooling (d). b. Red. design margins (i). c. Reduce F/E (i). d. Incr. stability limits.
	Incr. Th. Isp 6 sec.	e. Incr. Pc (i).
Increase F/W 100%	Incr. Isp. Eff. 5% Incr. Th. Isp 6 sec. Decr. weight 60%	a. - e. f. Lightweight materials (i). g. Eliminate stability aids. h. Red. manifold vol. (d).

*Quantitative amounts depend on design tradeoff studies

d - direct AFRL contribution, actual or planned i - indirect contribution

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Relationshop to IHRPT Goals

B&OT Goal:	C&EC Tech. Obj.	Inj./Comb. Task*:
Red. failure rate 75%	Red. part count 75%	a. Red. parts count (d).
Red. costs 35%	Red. costs 38%	a. Red. parts count (d). b. Red. handworking (i). c. Relax tolerances (d).

- AFRL will suggest solutions and provide subscale windowed testing support for IHPRPT injector/combustor development.
- Overall lead for injector/combustor design should remain with the contractors.

Subscale hot fire facility

Propellants

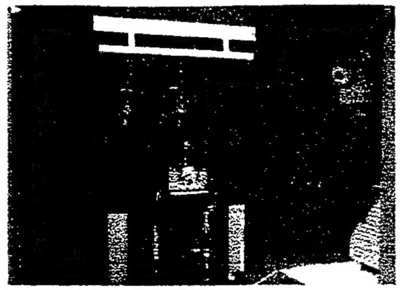
Fuel	H_2(g), CH_4(g)
Oxidizer	O_2(g)
Purge gas	N_2(g), He(g)
H2 mass flow rate	.15 lbm/s (.07 Kg/s)
CH4 mass flow rate	.25 lbm/s (.11 Kg/s)
O2 mass flow rate	1.0 lbm/s (.45 Kg/s)
N2 mass flow rate	.5 lbm/s (.23 Kg/s)
Water flow rate	16 lbm/s (7 Kg/s)
Max. system press.	2640 psi. (179 atm)

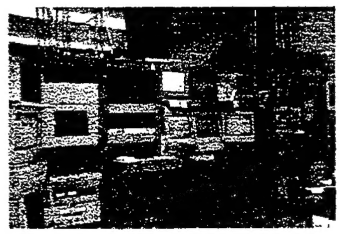
Data acquisition and control

VXI bus, MXI-interfaced to PowerPC with 48MB RAM and optical drive.
HP 1413B 64ch 100kHz scanning A/D board with signal conditioning modules.
Tektronix 16 ch 200kHz /ch A/D board.
VX4353 32 ch SPST relay switch card.

Optics

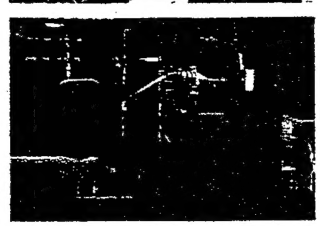
20 kHz, 20W Cu vapor laser.
Innova 4W and 10W Argon Ion lasers.
Inj. seed, 2 plse Yag (1.5J at 1064 nm)
Continuum ND6000 Dye laser.
Princ. Inst and Stanford gated CCD cams.
Infinity and Questar LD microscopes.
Aerometrics 2 comp. PDPA.





Optically Accessible Rocket Engine

- Gas/Gas engine. Similar to Penn State Optically Accessible Engine
  - H2 fuel, O2 oxidizer. Capability for other fuels.
- FY99 Accomplishments
  - Demonstrated successful firing.
  - Began heat transfer analysis to prepare for insertion of quartz viewing windows.
  - Heat transfer work suspended to prepare for PDRE testing.
- FY00 Tasks
  - Complete heat transfer analysis.
  - Raman imaging of chamber to compare with Penn State results.
  - Biasing of O2 injector.



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HFTF Upgrades in 1999

- Replaced stainless steel tubing and fittings in GOX system with monel
- GOX system cleaned by NTS
- Installed filters in all systems
- Acquired parts for hydrocarbon system
- Acquired altitude chamber
- Improved data transfer rates with Ethernet switch
- Improved flexibility of Abort System Software
- Upgraded main control computer to Mac G3

Planned for 2000

- Complete liquid hydrocarbon system
- Procure and install LOX system

Single element cold flow pressure facility

Gas simulants	N_2(g), He(g)
Liquid simulant	H_2O(l), others
Window Purge gas	N_2(g), He(g)
N_2 mass flow rate	.20 lbm/s (.09 Kg/s)
He mass flow rate	.20 lbm/s (.09 Kg/s)
H_2O mass flow rate	4.0 lbm/s (1.8 Kg/s)
Max. test art. press.	2000 psi (136 atm)
Max. Fuel sim. press.	3000 psi. (204 atm)
Max. Ox sim. press.	3000 psi. (204 atm)

Windowed test chamber with 5.5" (14 cm) of axial injector travel and a linear translating injector stage with 5" (13 cm) total radial travel inside chamber.

Ability to simulate manifold cross velocities to 30 ft/s (9.1 m/s).

27 tube traversable mechanical patternator

Phase Doppler, Malvern, other diagnostics

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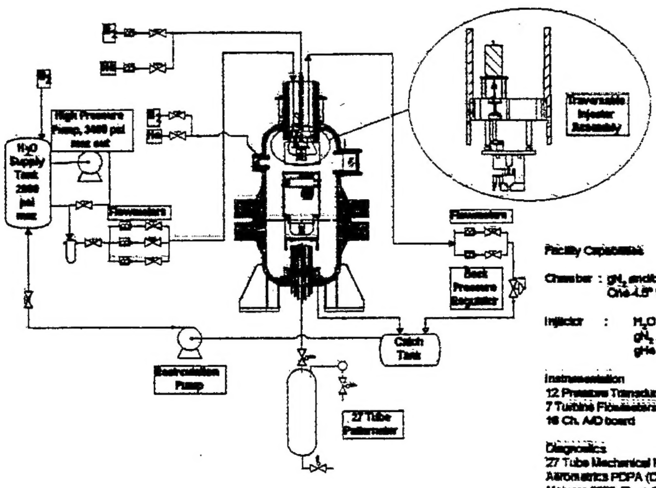
High Pressure Cold Flow Facility



Facility Capabilities

Chamber : gN_2 and/or gHe 2000 psi max
One 4.5" window, Three 2.0" windows

Injector : H_2O 3000 psi max, 4 lb/s
gN_2 3000 psi max, 0.20 lb/s
gHe 3000 psi max, 0.20 lb/s

Instrumentation
12 Pressure Transducers : $P_{chamber}$, dP_{water}, dP_{gas}
7 Turbine Flowmeters: Q_{water}, Q_{N2}, Q_{He}
16 Ch. A/D board

Diagnostics
27 Tube Mechanical Patternator
Aerometrics PDPA (Drop Size Distribution and Velocity)
Malvern 2600 (Drop Size Distribution)
Coaxial Beam Particle Analyzer (Drop Size Distribution and Velocity)

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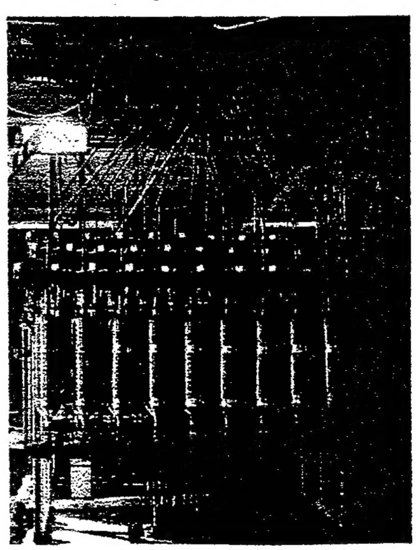
Automated Patternator System FY99

Spray mass distribution is critical to:

- propellant mixing
- combustion efficiency
- wall compatibility

New system greatly increases speed at which spray mass distribution data can be collected.



Past Systems Supported by Cold Flow Facility

SSME hot gas manifold model
Fastrac main injector
SSME/RLV preburner injector comparison
Proprietary A
SSME preburner post bias tests

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FY99 Accomplishments

- PDPA small probe volume development.
  - 2 ILASS and 2 *Atomization and Sprays* publications
- SSME post biasing studies (with Rocketdyne).
  - 35th JPC, *Journal of Prop. and Pow.*
- Proprietary B
- Orifice hydraulics study.
  - *Atomization and Sprays*
- Low cost injector study (partly proprietary).
- Automated Patternator upgrade.
- 3400 psi fluid pressure upgrade.

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The Effects of LOX Post Biasing on SSME Injector Wall Compatibility

AIAA 99-2888

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Air Force Research Laboratory, Edwards AFB, CA

L. K. Tseng and K. I. Miner
Rocketdyne Propulsion & Power, The Boeing Company, Canoga Park, CA

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Motivation

- High efficieny engines require high chamber pressure and throughput.
- Problems:
  - High Heat Flux
  - Oxidative Attack (LOX)
- Wall protection methods;
  - Film Cooling
  - Mixture Ratio Biasing
  - LOX Post Biasing
- The result is Isp loss due to MR non-uniformity in the engine.
- Goal : Provide a detailed understanding, through cold-flow simulations of the effects of LOX post biasing on the liquid and gas phase distribution near a wall.

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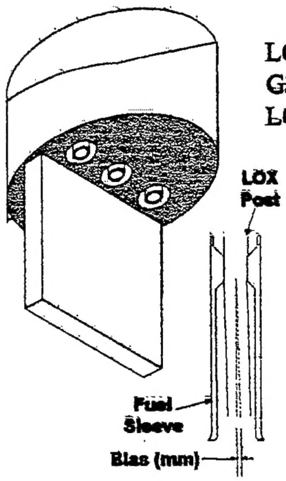
Scaling Parameters



LOX Post ID=4.77 mm
Gas Gap=2.24 mm
LOX Post Recess=6.35 mm

Parameter	SSME (LOX/gH_2+H_2O)	Cold-Flow (H_2O/gN_2)
Pc (MPa)	19.3	0.74
Liq. Vel. (m/s)	31.3	10.0
Den. Ratio(l/g)	117.6	117.6
Vel Ratio (l/g)	0.087	0.087
Mom Ratio (l/g)	0.286	0.286
Mix Ratio (l/g)	3.25	3.25
Liq. Re #	$1.1e^6$	$4.3e^4$

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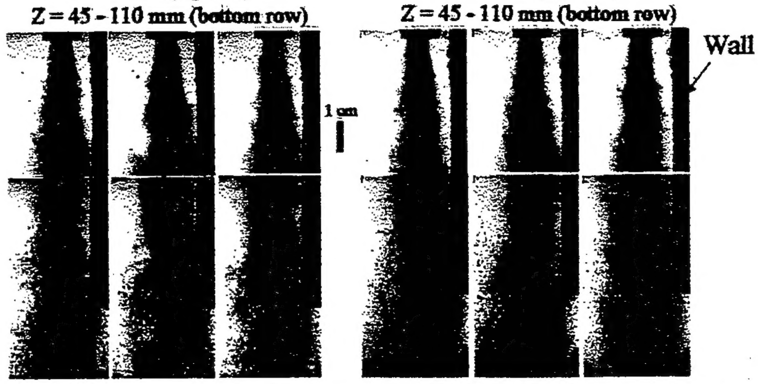
Strobelight Imaging

Biasing shifts the liquid flow away from the wall.

Unbiased	Biased 0.48 mm
Z = 0 - 45 mm (top row)	Z = 0 - 45 mm (top row)
Z = 45 - 110 mm (bottom row)	Z = 45 - 110 mm (bottom row)



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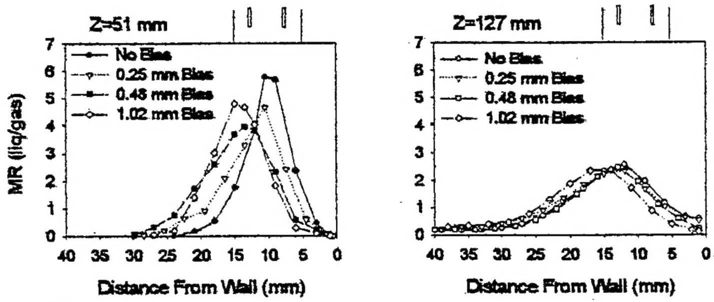
Mixture Ratio Profiles

- Mixture ratio distribution is "shifted" away from the wall with LOX post biasing.
- The shift is due to a combined result of the displacement in liquid distribution away from the wall and an increase in gas flow on the wall side of injector.



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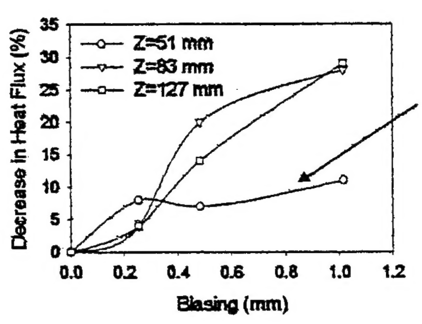
Heat Flux Analysis

- Gas-Gas studies have shown a similitude between cold-flow data and hot-fire data at equivalent residence times.
- For the SSME, t=1 ms, approximately equivalent to the 51 mm cold-flow data.



$q'' \propto V^{0.8} \cdot T_g$

$T_g = f(MR)$

As $V \uparrow$ $T_g \downarrow$

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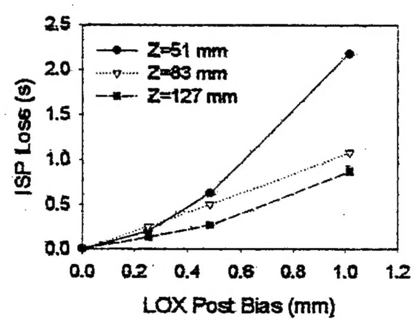
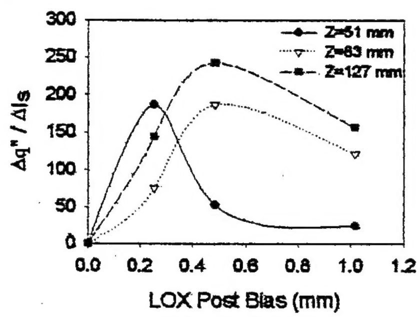
Performance Analysis

- ISP loss for SSME (Bias=0.48 mm) between 0.3 and 0.6 s.
- Δq"/ΔIsp optimized at a Bias between 0.25 and 0.48 mm.





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Conclusions

- LOX post biasing results in displacement of liquid flow away from the wall, and higher gas velocity near wall. Net result is a decreased MR near the wall.
- Isp loss increases with increasing LOX post bias.
- Some reduction in bias could recover a small amount of Isp, while still providing adequate wall protection.
- Optimization curves can aid injector designers in choosing a level of biasing.
- Droplet size should not play a large role.

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Planned for FY00

- Extend post biasing studies to hot fire
  - Reproduce and extend Penn State gas/gas coax data
    - Duplicate hardware checkout initiated in FY99 but discontinued to support PDRE work.
    - Raman measurements to be attempted closer to the injector face.
  - Develop GOX post bias data for code anchoring
- Facility upgrades: liquid hydrocarbon and LOX capability
- Low cost injector design studies (proprietary)
- High pressure impinging injector measurements

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Summary

- Strategic vision
  - *Provide design guidance before committing to full scale hardware. Reduce trial-and-error expenses.*
- Unique facilities
  - Cold flow, hot fire and supercritical
  - High pressure, optically accessible
- Relevance
  - *<u>Short term</u>: problem turnaround on industry time scales (e.g., months)*
  - *<u>Long term</u>: Validated models will apply universally.*
- Accomplishments
  - *Numerous real-world engines impacted.*
  - *Numerous other metrics accomplished (publications, awards, tech transfer, etc.)*